

White Paper Recommendations to Address Flaring Issues, Solutions and Technologies

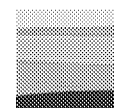
Updated September 2019

DRAFT

**FOR MORE INFORMATION
PLEASE CONTACT:**

**ANDRA WILCOX
AWILCOX@HARC RESEARCH.ORG
281.364.6036**

**RICH HAUT
HAUT@HESTLLC.COM
281.787.8768**



HARC

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DRAFT

*This material is based upon work supported by the Department of Energy National Energy Technology Laboratory under Award Number **DE-FE0031691**.*

CONTENTS

[TOC \O "1-3" \H \Z \U]

DRAFT

EXECUTIVE SUMMARY

In May 2015, the Environmentally Friendly Drilling Systems (EFD) Program, managed by the Houston Advanced Research Center (HARC) published the White Paper, “Recommendations to Address Flaring Issues, Solutions and Technologies.” This study was funded, in part, by the U.S. Department of Energy (DOE) through the Research Partnership to Secure Energy for America (RPSEA) technology integration program.

The objective of that paper was to provide information and summarize technology as new state and federal regulations were being promulgated to reduce flaring and venting of natural gas. The primary focus was independent oil and gas producers and policy makers. The paper was provided to the DOE and RPSEA enabling them to identify opportunities for R&D funding that would help reduce emissions from oil and gas operations and create a return on these investments through royalties, taxes and jobs.

Much has changed since 2015. New rules have passed, commodity prices have fluctuated significantly, and emissions from oil and gas operations have been reduced. With the change in Administration, variation in oil price, opening of gas exports, change in regulations and the revised OOOOa rule, the amount of natural gas production has increased, with more being used for electrical generation.

This update of the White Paper offers the DOE and the National Energy Technology Laboratory (NETL) the opportunity to provide valuable, possibly critical information through meaningful discussion with the U.S. Environmental Protection Agency (EPA), States, U.S. Department of Interior (DOI) and the Bureau of Land Management (BLM). Throughout the workshops that were held, information was exchanged among a broad audience of stakeholders, including operators, service providers, academia, NGO’s, federal and state government agencies and regulators. This update gives NETL access to timely information that may be used to focus research, development and deployment efforts to increase resiliency within both the upstream and midstream oil and gas industry in areas of safety and efficiency.

As stated in An America First Energy Plan, ‘the Trump Administration is committed to energy policies that lower costs for Americans and maximize the use of American resources, freeing our nation from dependence on foreign oil. In addition to being good for our economy, boosting domestic energy production is in America’s national security interest, our need for energy must go hand-in-hand with responsible stewardship of the environment.’¹

There are many opportunities to monetize stranded and flared gas, while continuing to reduce emissions. The Nation’s oil and gas abundance, powered by horizontal drilling and hydraulic fracturing, has driven down the cost of energy. These technological advances have made the United States a dominant producer of natural gas, so much so that supply far exceeds domestic demand. Allowing U.S. producers to meet global demand incentivizes production and enables investment in infrastructure throughout the upstream and midstream oil and gas industry. By exporting some of the surplus natural gas, the U.S. can help trading partners move to a cleaner energy source. Natural gas is no exception to the laws of economics where the benefits of free trade far exceed the costs. In this case, the benefits of natural gas exports are economic, environmental and geopolitical – all at the same time.

¹ <https://www.heartland.org/publications-resources/publications/an-america-first-energy-plan>

The objectives of this project were:

1. Hold a series of workshops to identify current most applicable practices to mitigate flaring and maximize the value of natural gas at the wellhead, as well as barriers that prevent these practices from being applied.
2. Identify technologies that are currently being used as well as those that are currently being developed and determine their applicability to reduce emissions associated with natural gas production.
3. Identify research, development and demonstration of technologies needed to further advance cost-effective solutions to boost domestic natural gas production and provide responsible stewardship of the environment throughout the upstream and midstream oil and gas industry.
4. Identify recommendations related to research needs.
5. Provide an updated White Paper that will identify policy barriers, as well as identify opportunities for research and development funding that would help reduce emissions from oil and gas operations, and create a return on these investments through royalties, taxes and jobs.

Infrastructure remains a key issue and is a major critical path item. Efforts need to be directed to enable early installation of infrastructure (gathering lines, power lines, etc.). In addition, infrastructure regulations vary by region, there is a need for process to exchange ideas and practices between policy makers.

To address various flaring aspects, states need to make it a priority goal, and some have. Regulatory bodies within a state will need to work together, including oil and gas commissions, department of natural resources, environmental agencies, public utility and commissions where regulations and regulatory issues on forming co-ops need to be addressed.

Technologies associated with mitigating flaring can be synergistic with other emission-mitigation efforts. Demonstration of technologies need to be performed to explore the synergies and to enable economics of various options to be determined.

INTRODUCTION – MONETIZING STRANDED GAS

The Nation's oil and gas abundance, powered by horizontal drilling and hydraulic fracturing, has driven down the cost of energy. These technological advances have made the United States a dominant producer of natural gas, so much so that supply far exceeds domestic demand. Allowing U.S. producers to meet global demand incentivizes production and enables investment in infrastructure.

Keeping abundant natural gas production in the U.S. does not provide protection or insulation to consumers. Over time this approach to try and protect consumers only weakens the U.S. position globally.

Data from the International Energy Agency show that increased use of natural gas worldwide could lower global carbon dioxide emissions by 740 metric tons in 2035 – more than the carbon dioxide emitted by France, Canada or the United Kingdom in 2012. By exporting some of the surplus natural gas, the U.S. can help trading partners move to a cleaner energy source. Natural gas is no exception to the laws of economics where the benefits of free trade far exceed the costs. In this case, the benefits of natural gas exports are economic, environmental and geopolitical – all at the same time.

As regulations related to the flaring of associated gas during production of oil wells across the country continue to influence operations, the oil and gas industry operators are faced with potentially having to install and utilize equipment aimed at the reduction of emissions from natural gas flaring. While natural gas flaring is seen as a considerably less polluting alternative to venting methane directly into the atmosphere, new rules from states and the EPA will ultimately force operators to find an alternative to the flaring of natural gas.

Flares play an important safety role at facilities, providing safe and effective means for burning the gases during well completions and emergencies. Where continuous flaring is occurring, there is a preference for the flare to be mitigated or eliminated. Everyone wants to capture this resource. The energy industry is continuing to advance effective solutions. Identifying and implementing the most cost-effective method for mitigating continuous flaring requires adequate, accurate operational data, a clear understanding of normal operating conditions and the selection of the appropriate technology and provider.

The process dubbed ‘green completion’ or ‘reduced emissions completions (REC)’ promotes the use of stranded gas by employing various technologies available in the marketplace. For most operators, however, evaluating these technologies, reviewing alternatives and selecting the correct one for that particular region can be a daunting task.

The Houston Advanced Research Center (HARC) teamed up with RPSEA to address the issue of gas flaring and stranded gas by documenting the use of existing technologies aimed at monetizing gas at the wellhead. Recognizing the aforementioned regulations as well as the economic benefits of capturing flare gas, the overall objective of the Flaring Issues, Solutions and Technologies (FIST) project is to identify, develop and demonstrate technologies specifically designed to use stranded gas and to reduce or eliminate the need to flare emissions associated with oil production. In other words, HARC and RPSEA hope to help operators make money from their stranded gas while conforming to new rules. This report identifies various technologies operators are using today to reduce flaring. While the report shows there is no “best” solution(s), there are underutilized options available.

As the FIST initiative evolved, it became clear the issues associated with gas flaring vary across regions, and are more pressing than anticipated, with complex regulatory, economic and infrastructure issues. This study enabled the identification of technical and potentially economic solutions that need to be further investigated, demonstrated, and transferred.

RECOMMENDATIONS

Based on information gathered to date, it is recommended that the following items be addressed.

- Infrastructure is a key issue and is a major critical path item. Efforts need to be directed to enable early installation of infrastructure (gathering lines, power lines, etc.). In addition, infrastructure regulations vary by region, there is a need for process to exchange ideas and practices between policy makers. There are two critical studies that should be performed:
 1. Options should be investigated and documented concerning how operators and regulators may be proactive in order to develop a fast track/streamline process.
 2. Develop a GIS tool that may be used to assist infrastructure decisions and development plans.
- To address various flaring aspects, states need to make it a priority goal, and some have. Regulatory bodies within a state will need to work together, including oil and gas commissions,

department of natural resources, environmental agencies, public utility and commissions where regulations and regulatory issues on forming co-ops need to be addressed. The Interstate Oil and Gas Compact Commission (IOGCC) is in an excellent position to lead this effort. Workshops and forums should be organized to pull these organizations together. Specific items that these task groups need to consider are:

1. Address barriers to access gathering and power lines.
(These could be state or local specific.)
 2. Emission/Air Quality Credits.
 3. Financial incentives from states to offset their investment in new solutions.
(This should be temporary.)
- Technologies associated with mitigating flaring can be synergistic with other emission-mitigation efforts. Demonstration of technologies need to be performed to explore the synergies and to enable economics of various options to be determined. Multiple options need to be investigated to handle the regional variations that exist.
 - To assist operating companies in risk management and the decision-making process, further work should be undertaken to develop a decision management system to screen technologies related to mitigating flaring. This should include:
 1. Evaluation of technologies that mitigate flaring including:
 - Transformation of stranded gases into salable products
 - Reduction of emissions in a cost-effective manner
 - Determination of how technologies and processes could further advance exports of hydrocarbon commodities
 2. Analysis of field results of selected technologies that producers may use to mitigate flaring, including emissions measurement.
 3. Providing useful compilation information and data for operators, regulators and landowners. Have a process available to address the regional geographic and geologic challenges that range for variability of gas quality, quantity, access to transportation via gathering and pipelines, transmission lines for transporting gas to power as well as other means to move energy from production sites to users.
 4. Expansion/re-organization of the Intermountain Oil and Gas BMP Project site to include best available technologies on a regional basis. Additional funding would be required to transfer the site to HARC.
 - States and federal agencies need to provide leadership, partnering with each other, to provide incentives to address the barriers identified, to make smart research and development investments, to fast-track infrastructure development and to promote communication among industry, regulators and agencies.

PROJECT OVERVIEW

In August 2014, the Environmentally Friendly Drilling Systems (EFD) Program, managed by the Houston Advanced Research Center (HARC) conducted a thorough review followed by a series of workshops across the country concerning flaring mitigation and reduced emissions. Workshop participants included operators, service providers, and a broad audience of stakeholders including academia, regulators and NGO's. These meetings explored specific needs and issues related to operations related to monetizing natural gas at the wellhead. The overall objective was to identify technologies to monetize stranded gas and

reduce or eliminate gas flaring and/or methane emissions associated with production. Additional objectives of this effort were to:

- Determine the extent of gas flaring/stranded gas in various basins
- Summarize state regulations regarding gas flaring
- Identify barriers that slowed use of stranded and flared natural gas
- Identify and introduce proven technologies, practices and processes currently in use to address the problem and monetize gas at the wellhead

The resulting White Paper from the workshops, “*Recommendations to Address Flaring Issues, Solutions and Technologies*” provided information, gives recommendations and summarizes technology as new State and Federal Regulations were being promulgated to reduce flaring and venting of natural gas. The primary focus of the effort were independent oil and gas producers and policy makers. The paper was provided to the US Department of Energy (DOE) and RPSEA, so they could identify opportunities for research and development funding that may help reduce emissions from oil and gas operations, and create a return on these investments through royalties, taxes and jobs.

The paper was released through industry meetings, publications, with thousands of downloads from the efdsystems.org website. The paper identified opportunities, technologies as well as barriers for adaptation.

Much has changed since the release of the White Paper. New rules have passed, commodity prices have fluctuated significantly, and emissions from oil and gas operations have been reduced. While natural gas production increased more than 50 percent from 1990-2017, methane emissions from natural gas systems decreased 14 percent. Overall U.S. methane emissions decreased 15 percent.² With the change in Administration, change in oil price, opening up of gas exports, change in regulations, the OOOOa rule, the amount of natural gas that is now used for electrical generation and other items, the Project Team determined to develop an update of the White Paper.

The updating of the information will provide the U.S. Department of Energy (DOE) and the National Energy Technology Laboratory (NETL) the opportunity to provide valuable or possibly critical information to the U.S. Environmental Protection Agency (EPA), U.S. Department of Interior (DOI), the Bureau of Land Management (BLM), and states in meaningful discussion with the latest update. Additionally, the results from this report may be used by NETL to focus research, development and deployment efforts to increase resiliency within the upstream and midstream oil and gas industry in areas of safety and efficiency.

IDENTIFYING THE ISSUES

Issues associated with gas flaring vary across regions, are complex regulatory, economic and infrastructure issues. State and Federal regulators have identified the need for information. The relevance is highlighted by the Bureau of Land Management’s (BLM’s) February 8, 2016 “Waste Prevention, Production Subject to Royalties, and Resource Conservation” Proposed Rule at 81 FR 6616. On February 22, 2018 BLM published Waste Prevention, Production Subject to Royalties, and Resource Conservation; Rescission or Revision of Certain Requirements. This revision was in part due to the Trump Administration E.O. 13563 and the principles of E.O. 12866 that requires agencies, among other things, to “identify and assess available alternatives to direct regulation, including providing economic incentives to encourage the desired behavior, such as user fees or marketable permits, or providing information upon which choices can be made by the public.” The 2016 final rule established requirements and direct regulation on operators. The

² API

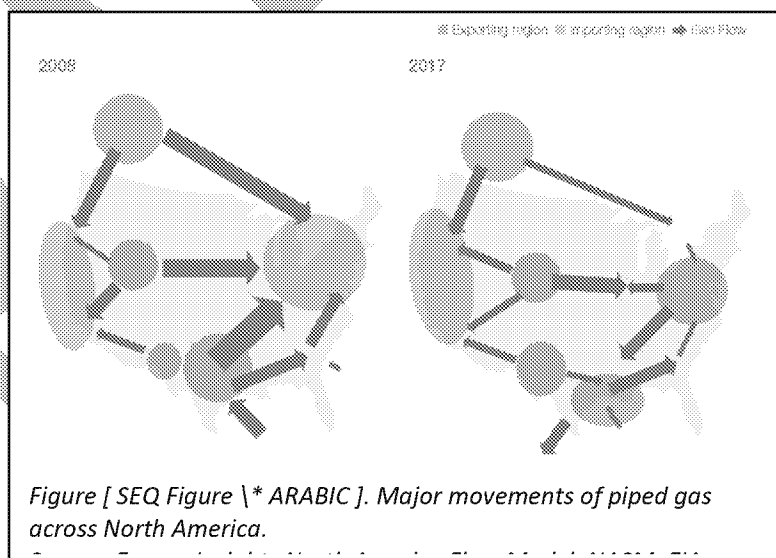
BLM stated that if the proposed rule were finalized, the BLM would remove the requirements of the 2016 final rule that impose the most substantial direct regulatory burdens on operators.

The BLM requested comment on ways that the BLM (and the industry) can reduce the waste of gas by incentivizing the capture, reinjection, or beneficial use of the gas. The BLM is interested to learn of best practices that could be incorporated into the final rule that would encourage operators to capture, use, or reinject gas without imposing excessive compliance burdens that could unnecessarily encumber energy production, constrain economic growth, and prevent job creation. This need goes well beyond Federal Lands and extends throughout the U.S.; in particular to independent operators.

Some state rules and regulations have been revised while others are also being reviewed. For example, New Mexico's Environmental and Energy Minerals and Natural Resources departments were ordered to create a new regulatory framework to control methane as part of a broad executive order for state agencies to work on reducing greenhouse gas emissions by 45 percent below 2005 levels by 2031.³ Colorado and North Dakota also revised their rules in April 2018.

Changing the Flow of Gas

As illustrated in [REF_Ref13655268 \h * MERGEFORMAT], growing shale production from northeast has changed how gas flows in the United States.⁴ In 2008, natural gas in North America came mainly from the Gulf Coast / Mid-Continent, Western Canada and the Rocky Mountain regions. By 2016, growth in unconventional production made the Marcellus / Utica the largest gas producing area and growing market demand in the south reversed the direction of flow from north to south. In addition, exports to Mexico changed the flow direction in South Texas. The Permian and Appalachia basins will supply approximately 55% of the North American gas market by 2030. The majority of the expected North American gas demand is linked mostly to projected LNG exports. US LNG export capacity is expected to remain high (80-90%) through 2024.



U.S. LNG Export Capacity Continues to Increase⁵

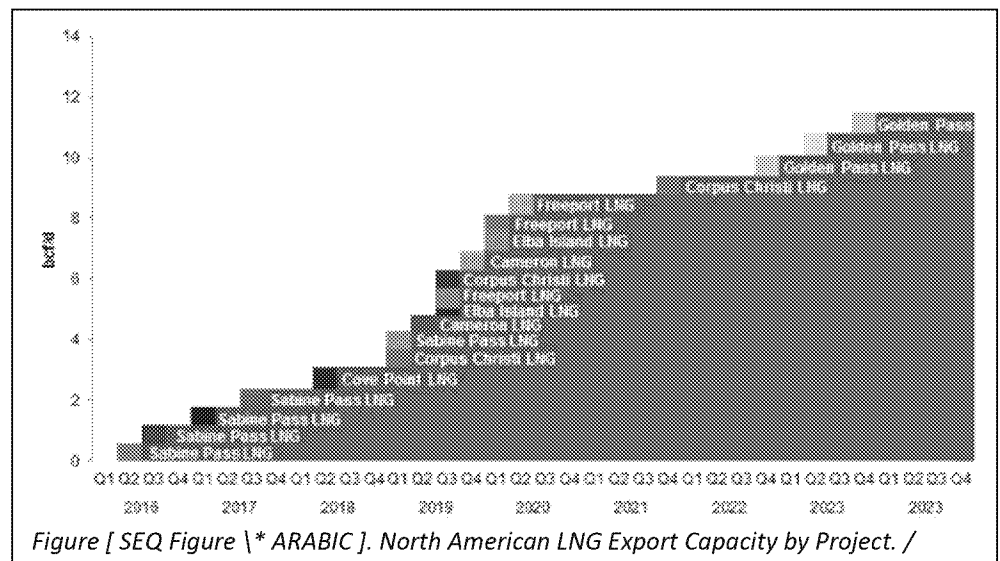
According to EIA, the export capacity of liquified natural gas (LNG) will reach 8.9 Bcfd by the end of 2019. This makes it the 3rd largest globally, after Australia and Qatar. An overview of export capacity is given in Figure 2.

³ Robinson-Avila, Kevin, "Hot Debate on Methane Emissions has Begun," July 1, 2019.

⁴ McKinsey Energy Insights, North American Gas Perspectives Summary Outlook, June 2018.

⁵ [HYPERLINK "<https://www.worldoil.com/news/2019/1/1/eia-us-lng-export-capacity-to-more-than-double-by-the-end-of-2019>"]

The U.S. began LNG export from the Lower 48 in 2016 (February) with the first cargo shipment from the Sabine Pass liquefaction terminal in Louisiana. Since then several other projects have been completed or are expected to be in service by the end of 2021, as illustrated in Figure 2. These include:



- Sabine Pass expansion from one to four liquefaction trains
- Maryland's Cove Point
- Sabine Pass Train 5
- Corpus Christi LNG Train 1
- Cameron LNG in Louisiana
- Freeport LNG in Texas
- Elba Island LNG facility near Savannah, Georgia
- Second train at Corpus Christi LNG
- Freeport Train 3 (2020)
- Corpus Christi Train 3 (2021)

Four additional export terminals—Magnolia LNG, Delfin LNG, Lake Charles, Golden Pass—and the sixth train at Sabine Pass have been approved by the U.S. Federal Regulatory Commission and the U.S. Department of Energy, and, if constructed will provide an additional LNG export capacity of 7.6 Bcf/d.

In most outlooks, exports of natural gas are projected to increase due to the net supply and demand for natural gas. Additional infrastructure will be needed to support such exports as well as the economic benefits they bring to the United States. The infrastructure for oil will largely be increased marine terminal and waterway capacity. For natural gas, most of any increase is expected to be marine shipments of LNG, though some gas is exported to Mexico and Canada via pipeline currently. Additional terminal, storage and/or waterway capacity will be required for LNG exports as well as increased pipeline capacity from producing fields to new terminals. summarizes current LNG export projections.

It is not possible to predict specific future infrastructure needs precisely. This is especially true when considering needs in the next several decades. Providing likely regulatory and permitting frameworks, however, enables companies to better adapt and respond as situations arise. Necessary investment in infrastructure includes the availability of skilled construction labor and materials, along with cohesive permitting processes.

Flared Gas Data

Domestically, flaring has become more of an issue with the rapid development of unconventional, tight oil and gas resources over the past two decades, beginning with the development of unconventional / shale gas. Unconventional development has brought online hydrocarbon resources that vary in their characteristics and proportions of natural gas, natural gas liquids and crude oil. While each producing region flares gas for various reasons, ***the lack of a direct market access for the associated gas with oil production is the most prevalent reason for ongoing flaring***. Economics can dictate that the more valuable oil be produced and the associated gas burned (or reinjected) to facilitate that production. Until transmission, storage, and delivery infrastructure increases in these newer or expanding producing regions, flaring and venting will continue to represent environmental issues and lost market opportunities. Of specific importance has been the increase in flaring of gas associated with oil production in liquids rich plays where there is not enough gas gathering and transportation infrastructure to enable the gas to be marketed.

The U.S. Energy Information Administration (EIA) obtains data on flaring and venting volumes from producers and certain producing states that collect this data to share. EIA's compiled data show the reported volumes of flared gas have reached levels between 225 and 285 billion cubic feet per year in the 1990's. This level dropped to almost half of this amount during the early 2000's. Since then, however, flared volumes reported have matched and surpassed earlier amounts, averaging 200 and 300 billion cubic feet annually during 2011 to 2017. This coincides with both oil and gas production significantly increased levels.

As listed in [REF_Ref13658148 \h * MERGEFORMAT], from 2010 to 2013 the amount of gas flared reported to EIA in the U.S. increased by 94,466 MMcft, while total reported gas produced increased by 2,736,466 MMcft. Then, from 2013 to 2017 the amount of gas flared reported in the US decreased by 24,824 MMcft, while total reported gas produced increased by 3,804,424 MMcft.

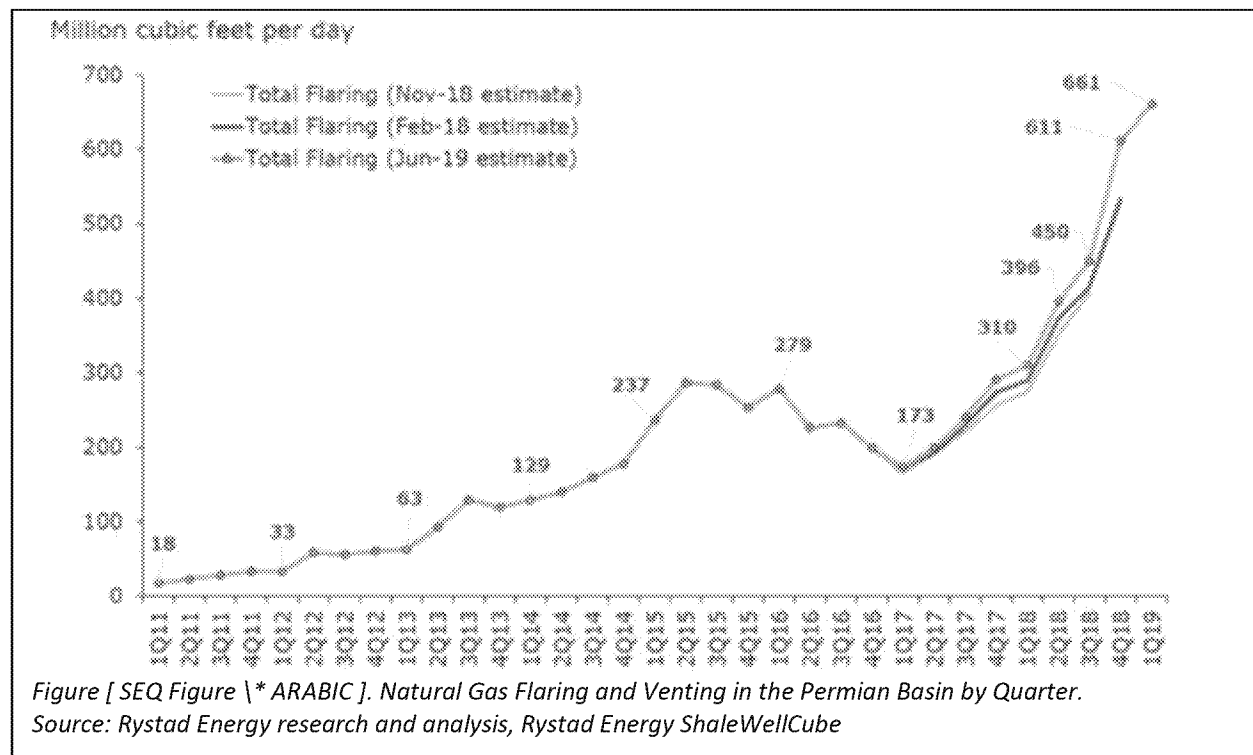
Table [SEQ Table * ARABIC]. Reported Gas Volumes. (Source: EIA)

	Total Flared Gas (MMcft)			Total Produced Gas (MMcft)			Ratio: Flared/ Total Produced		
	2010	2013	2017	2010	2013	2017	2010	2013	2017
Total US	165,928	260,394	235,570	26,816,085	29,552,551	33,357,375	0.6%	0.9%	0.7%
North Dakota	24,582	102,855	88,504	113,867	347,787	688,605	21.6%	29.6%	12.9%
Texas	39,569	76,113	101,001	7,565,123	8,299,472	7,995,736	0.5%	0.9%	1.3%
Wyoming	42,101	34,622	9,132	2,514,657	2,047,757	1,804,681	1.7%	1.7%	0.5%
Other States	59,676	46,804	36,933	16,622,438	18,857,535	22,868,353	0.4%	0.2%	0.2%

Texas and North Dakota have seen increased flaring. Both states are working with producers to limit the need for flaring without impacting production of oil from new wells. These two states have notably increased unconventional oil development with significant volumes of associated gas production within the Eagle Ford and Permian in Texas and Bakken Shale Play in North Dakota. Venting and flaring of gas in the U.S. is concentrated in the Permian and Bakken currently, with the Bakken levels indicating around 500 MMcfd in first quarter of 2019. This brings the total volumes of vented and flared gas from the two basins to approximately 1.15 billion cubic feet per day

Without the option of flaring and/or venting, which allows operators a 'relief valve' to continue oil production, operators may find themselves forced to shut in production due to lack of infrastructure. In the Permian Basin, flaring and venting has reached record high volumes in the first quarter of 2019, with an

estimated average of 661 MMcfd, according to research conducted by Rystad Energy as seen in [REF _Ref13647595 \h * MERGEFORMAT].⁶



During the first quarter of 2019, flaring of natural gas in the Permian reached an all-time high, averaging 661 MMcfd. As a comparison, Royal Dutch Shell operates the Mars-Ursa complex in the Gulf of Mexico, which is the most productive gas facility in the region. The Mars-Ursa complex produces 260-270 MMcfd of gas. The amount of gas which is flared in the Permian more than doubles the amount produced at the most productive facility in the region. The Permian is expected to flare roughly 650 MMcfd until the second half of 2019 when Kinder Morgan's Gulf Coast Express pipeline comes online.

Williams, a pipeline operating company, is challenging Exco Resources request to flare the gas produced from a group of South Texas wells. In the past seven years, the Texas Railroad Commission has granted more than 27,000 flaring permits. Exco has stated that without the permit, the wells may be shut-in. Natural-gas pipeline construction in Texas has lagged behind production growth, in part because producers have been reluctant to commit to long-term contracts. The Commission's decision will have consequences. Restricting flaring may cause oil production to be curtailed and give pipeline companies additional leverage to secure contracts and build new infrastructure. Granting flaring permits in cases such as Exco's may make pipeline companies less willing to risk building new infrastructure. Economics are important – is it less expensive to flare gas than to pay for transportation?⁷

Bakken producers flared 527 MMcfd, or 20%, of all the gas produced during October 2018, according to data released by the North Dakota Industrial Commission. It was the most gas flared in the state on record and largest percentage flared since August 2015. Although natural gas flaring in the Bakken Shale set records

⁶ "Permian gas flaring, venting reaches record high," Oil and Gas Journal, June 4, 2019.

⁷ Elliott, R.: "Texas Showdown Flares Up Over Natural Gas Waste," The Wall Street Journal, July 17, 2019.

in 2018, those levels are decreasing as processing plants come online. Oasis Midstream's Wild Basin plant has been expanded from 80 MMcfd to 260 MMcfd. Four additional large-scale processing plants are expected to be completed in 2019, adding a combined 690 MMcfd of capacity, more than the volume that is currently being flared. By the first quarter of 2020, a total of 1.23 Bcf/d of new gas processing plant and plant expansion is projected to come online, according to Platts Analytics.^{8,9}

ExxonMobil has announced plans to reduce the amount of natural gas flaring by 25% from 2018 to 2020. Their efforts will be focused on oil wells off the West African coast.¹⁰

International commitments have been made to end the practice of routine gas flaring by 2030. The Global Gas Flaring Reduction Partnership (GGFR) – initiated by the World Bank and the government of Norway in 2002 – was instrumental in the initiative. Countries and companies flare for various economic, regulatory and technical reasons. Endorsers of the initiative represent more than 40% of global gas flaring.¹¹ The initiative, along with other plans like ExxonMobil's, increases the market size and interest of flaring mitigation technologies.

FIST Workshops

A series of workshops were held in the 2013 – 2014 time period and were documented in the previous White Paper. A new series of workshops were held during the first part of 2019 to collect updated information. These workshops were held in Houston, Midland, Denver, and Canonsburg. The team learned in these workshops that there are a variety of more solutions to address flaring being applied today and the interest by the industry in identifying and applying economical solutions has significantly increased.

Each workshop began with an introduction to the Flaring Issues, Solutions and Technologies (FIST) 2019 project and team members. Recaps of prior workshop, literature and technologies' reviews and surveys were also shared. Participants at each workshop were invited to engage, ask questions, share thoughts (lessons learned, challenges, successes, etc.) as well as invited to review the updated paper during the project. Attendance at these workshops ranged between 40 and 75 individuals. PDFs of Technology Panels presentations will be available in Appendix of this paper.

Houston, Texas – March 19, 2019:

This first FIST workshop was hosted by Shell at their Woodcreek Training Center. The format was developed to help ensure interaction among all attendees. After the welcome and introductions from Shell's General Manager for Permian provided the welcome talk, discussing Shell's social license to operate being one of their strategic ambition pillars as well as the progressive stance Shell has taken on emissions. The speaker encouraged all attendees to participate and engage with each other.

The first session kicked off with a multi-stakeholder perspective discussion (**Issues**). A Shell air SME spoke about both struggles and opportunities associated with flaring profiles, about how flaring volumes are now tracked and discussed daily and the overall footprint of operations. They ask themselves where emissions

⁸ Evans, Brandon and Frey, Richard, "Bakken Processing Plant Expansion Helps Curb Natural Gas Flaring," [[HYPERLINK "https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/122818-bakken-processing-plant-expansion-helps-curb-natural-gas-flaring"](https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/122818-bakken-processing-plant-expansion-helps-curb-natural-gas-flaring)]

⁹ "Record Natural Gas Flared This Year in North Dakota," December 26, 2018. [[HYPERLINK "https://www.miamiherald.com/news/business/article223559070.html"](https://www.miamiherald.com/news/business/article223559070.html) \ | "storylink=cpy"]

¹⁰ Crowley, Kevin, "Exxon to Slash Gas Flaring 25% by 2020 in Emissions Push," May 23, 2018

¹¹ "Turning Gas into Cash," OPEC bulletin 5/15.

come from, what are restrictions of infrastructure and they came together through planning sessions to ask where they are going. Shell has cut flaring by 80% over last year.

The SME also shared Shell's Three Pillars, topics that were reiterated by many others (operators and service companies alike) over the course of the day.

- **Infrastructure:** All gas gathering is through 3rd party. It's very important to improve relationships and work closely with their 3rd party partners.
- **Technology:** This is the same as many others face – operability and reliability are key. How can we achieve less flaring (and how will such technologies help)?
- **Culture:** (This is the biggest, most impactful.) It's the boots on the ground people, there needs to be visibility, charts helped them see how much they are flaring, where they're flaring and why they're flaring. They now have flaring discussion meetings every day. Everyone needs to take ownership.

Stakeholders (operators, NGO's, service companies, etc.) around the room shared their experiences, questions and suggestions. Key points include:

- Flaring can be a bottleneck both at the wellsite as well as gas processing.
- Culture was repeatedly discussed as vital to mitigate flaring. Companies must get buy-in throughout operations, from entire asset.
- Companies must get all service providers, contractors and vendors "on the same page" as to the gas to reduce flaring.
- Much of the reduction in flaring came from elimination of flowback.
- Planning ahead helps address infrastructure challenges.
- Temporary infrastructure needs to be balanced with costs.
- Categorization – it's important to know where it's coming from, what the volumes are, where the most impact can be made.
- Consider what flaring looks like holistically.
- A key is measurement, knowing how much is being flared and what the causes are.
- Flexibility is needed regarding technology (portable, scalable, etc.).
- Don't just look at upstream, look at midstream process.
- Rapid decline in associated gas volumes are an important factor to consider.
- Changes in gas composition during the life of the well is a factor on solution decisions.

The next sessions focused on **Solutions and Technologies**, followed by Q & A.

Service Providers/Companies and Presentation Titles – **EcoVapor:** BTEX Destruction; **LPP Combustion:** Lean, Premixed & Prevaporized; **Capstone:** Microturbine Flare Gas Applications; **EcoVapor:** ZERO₂; **Ferus:** Mobile Flare Gas Capture & Marketing (CNG); **Heartland Water Technology:** Beneficial Use of Flare Gas for Evaporation; **Gulf Coast Green Energy:** Flare Gas to Power – Meeting Beneficial Use Requirements While Reducing Emissions.

Key points from the Technical Panels' session are as follows:

- LPP technology can be used for drilling, fracturing, EOR, micro-grids, power to utility grid and offshore platform power to generate power with liquid fuels (and reduced emissions).
- Capstone – Microturbines can operate on associated gas as alternative to flaring and can allow companies to monetize flare gas as a fuel source to generate power.

- EcoVapor eliminates need for VRT and combustor and because this can be moved so easily, it addresses the issue of rapid decline.
- Speakers agreed that culture and buy-in impacts adoption of technologies.
- Ferus: CNG for drilling applications, pressure pumping, frac water heating, injection, and integrated mobile gas network with numerous benefits. Pressure reduction unit needs to be economically and environmentally viable.
- Heartland: Technology uses thermal energy (flare gas) to treat water. Equipment only has 2 moving parts, can treat between 12k-150k gallons/day, no issues with T-NORM as they pull barium and radium, extract from bulk. System can be adjusted to meet client needs.
- GCGE: Shared results of DOE/HARC field trial with Hess in Bakken. Total run time was 2200 hours, total kWh produced was 110,000 – Emission reduction – CO down 89%, NOx down 48% and VOC down 90%. They have a radiator replacement (DOD) project – added 12% to output. Skid-mounted, can be moved inside of a day.
- GCGE and Heartland should work together. Strong synergy here. Speakers had not met each other before and this workshop provided the impetus to collaboration between them.

An ‘Around the Room’ Discussion was held wherein the moderator passed the microphone to each attendee. All were asked to share what was learned, what needs more research, and/or what would the attendees like to share. Key Points:

- What is amount of gas being flared?
- CO₂ feasibility
- To decrease flaring, how do you link outside monitoring with satellite?
- Collaborate with renewables like hydrogen
- Do these technologies apply to completions/fracturing?
- Challenges around microturbine adoption
- What is link between culture and compliance? How does a company self-regulate?
- Culture, culture, culture!
- Ask why we’re flaring, then ask how we approach this?
- Each of these technologies presented today has a place.
- Monetization for producer may lag but the technology is there.
- More diversity in well pad CO₂, small footprint water treatment.

To summarize key findings at Houston’s workshop:

Shell has reduced flaring in the Permian by 80% since 2017.

The Three Pillars are:

- Infrastructure – Working relationships with 3rd party partners is very important
- Technology – How can this contribute to reduced flaring? Operability and Reliability are crucial.
- Culture – (most important) Internal communications throughout organization, use of charts to help all remain on the same page. Hold everyday discussions / meetings to review/understand daily flaring volumes. Everyone has ownership

Midland, Texas – April 17, 2019:

This second FIST workshop was held at the Doubletree hotel in Midland, TX. Attendees included representatives from various operator companies including: Apache, Chevron, Noble, Diamondback E&P, Centennial Resources, Concho, EOG Resources, SM Energy and Pioneer. A few midstream companies also

attended such as Terra Midstream and Summit. Technology companies included panel members Capstone, EcoVapor, LPP Combustion, Questor Technologies and OTA Compression, LLC as well as attendees from HyBon, Heartland Technologies along with consultants and a representative from the Permian Basin Petroleum Association, a regional trade group that assisted with promotion of the workshop and FIST-2019 project.

The workshop format began with an opening/introduction, operators' perspectives (Issues), external stakeholder views, then technology panels followed by Q&A and around the room discussion.

The workshop opened with a representative from Apache Corporation sharing the company's approach to mitigate flaring, efforts they've pursued and lessons learned as they work to reduce flaring. He shared several implications of flaring including resource conservation, environmental impacts, financial impacts as well as public impact, stressing that this is the most important factor. He later shared what some companies view as alternatives to flaring such as reservoir storage, repressuring projects, injections (which is being done at gas plants), power generation and proration (which is not ideal). He then shared Apache's use of natural gas powered fracturing spreads, working with US Wells consisting of a 37 mW turbine generator. He shared the tremendous cost savings recognized with such an effort. Whereas a typical day with 9 stages can cost approximately \$60,000/day using diesel, their 37 mW turbine generator using NG costs around \$5000/day. This does not include the savings and safety benefits from reduced traffic supplying diesel to sites. Some of the benefits he stressed from this effort include reduced GHG emissions, noise and traffic along with the operational and reliability improvements encountered. Additional points include:

- Biggest bottleneck is finding alternatives because of gas line capacity; uses can be limited. Some may be able to go toward power generation.
- Long-term issues – gathering and getting it out
- Short term issues – finding alternative uses onsite
- Do what you're supposed to do, when you're supposed to do it, otherwise it'll be costly (not only financially, but also time-wise, environmental impacts, etc.)
- Grid is suffering also, power deliverability is a problem
- Rental of power generation equipment is costly
- Field gas may have been through compression but may not be pipeline quality
- Perhaps gas storage/injection is a long term solution (particularly in regard to depleted wells).
- One company is working on gas lift research with pilot tests (shale wells where production is almost depleted)
- Apache uses metering to track volumes.
- Audience member suggested not calling it 'disposal' because it's actually storage

A representative from Centennial Resources then spoke, reiterating that bottlenecks to reduce flaring relate particularly to infrastructure (getting it out to plants). Centennial also holds weekly/daily discussions to help plan and stresses the importance of strong relationships with partners such as midstream companies so that all are on the same page. He reminded all present to always consider drilling schedules and plan accordingly. Centennial also uses metering to track volumes.

Additional points:

- New Mexico is a bit more challenging because of the different state, federal and ROW issues. In some cases, it can take 6-7 months to resolve ROW factors.
- Centennial has tried on higher GOR, gas lift to address bottlenecks partly because of power needs in the area instead of subpump

- In power generation, turbine generators have been successful.
- In some areas, power lines are behind.
- Most meters are tied in with total flow

A stakeholder's perspective was shared through the University of Texas' McDonald Observatory. While not limited to impacts from flaring, the point was to share external stakeholders' views on impacts from development. O&G development activity in West Texas has brought changes to the university's ability to view the 'dark skies' due to increased and expanding lights from pad sites (along with the accompanying societal developments [hotels, housing, restaurants, etc.]). These impacts led to discussions with counties in which development was taking place (increasing) as well as with various companies active in the region. The takeaway is that all stakeholders play an important role to addressing issues and developing solutions to create a 'win-win' situation.

Technology companies presented (EcoVapor, Capstone, LPP, OTA and Questor Technologies) followed by Q&A. An 'around the room' discussion then took place. Key points:

- In the Permian Basin, RRC looks at quantity and environmental groups focus more on emissions.
- There are a lot of developing technologies to mitigate flaring.
- Helpful tools on power generation learned here.
- UL Incentive program should help get gas down the sales line.
- Attendees would like more information on reservoir storage option (as alternative to flaring).
- Attendees found the idea of 'huff and puff' and other alternatives interesting.
- There is no silver bullet to address this (flaring).
- These kinds of workshops are vital to tell what industry is doing, earn/keep license to operate. Attendee was glad this workshop brought operators, service companies and regulators together to talk.

To summarize the key findings at Midland:

Reduce Flaring Issues

- Infrastructure is a Bottleneck
- Culture (again, very important facet)
 - Weekly/daily discussions
 - Metering to track daily flaring volumes
 - Strong relationships with partners – midstream companies
- Alternatives to Flaring (Options)
 - Reservoir Storage
 - Repressuring
 - Use of Field Gas

Infrastructure remains a critical path item to address in order to alleviate bottleneck issues across the U.S.

Denver, Colorado – April 23, 2019:

The third FIST-2019 workshop was held at the Denver Athletic Club in Denver, CO on April 23, 2019. The format for this work differed from Houston and Midland schedules, which proved to be very productive.

The format was as follows:

Welcome/Introduction
Issues Panel Discussion
Stakeholder Panel Discussion
Technologies Panel Presentations
Around the Room
Wrap-Up

Attendees and panel members included representatives from industry (including *Anadarko*, EOG Resources, Encana, SRC Energy, ConocoPhillips, ExxonMobil/XTO, Jagged Peak, Great Western Operating, Slawson, Enerplus and local consultant organizations), regulatory/state agencies (such as *Colorado Oil & Gas Conservation Commission*, *Utah Department of Environmental Quality*, *Wyoming Oil and Gas Conservation Commission*, *Wyoming Department of Environmental Quality*, *Bureau of Land Management – Colorado Offices*, *Colorado Department of Public Health and Environment*, *North Dakota Energy and Environmental Research Center*, and the Environmental Protection Agency [Region 8]), technology companies (included panel members *Capstone Turbine*, *EcoVapor Recovery Systems*, *GCGE*, *LPP Combustion*, *Questor Technologies*, *GTUIT*, *Certarus* and *Heariland Water Technology*, Ferus and Horizon Power Systems), NGOs (Air Water Gas: Sustainability Research Network [who cohosted the event] and the *Environmental Defense Fund*) and academia (The University of Colorado – Boulder and the Colorado School of Mines). *Italicized organizations participated in the different panel discussions.*

After an operator presented their efforts to reduce emissions through facility design, planning and infrastructure, representatives from North Dakota EERC, Environmental Defense Fund, and BLM shared their take on addressing flaring mitigation. Again, insufficient infrastructure impedes flaring reduction goals. There is an MOU in the works between BLM and the Colorado Oil and Gas Conservation Commission. Attendee (operator) noted that incentives can and should be improved. Further, there needs to be a place for the low cost gas (demand side). Another attendee pointed out, regarding tankless facilities and/or centralized – if you're moving oil off the lease, it shrinks once you sell it to a 3rd party. BLM rule says operator must pay royalties – this may be a driver that keeps tankless off of BLM sites.

After the Issues Panel, speakers from the Colorado Oil and Gas Conservation Commission (COGCC), Wyoming Department of Environmental Quality (DEQ), Colorado Department of Public Health and Environment (CDPHE), Wyoming Oil and Gas Conservation Commission (WOGCC) and Utah DEQ presented from Regulatory Stakeholder perspectives. SB 181 had only recently been passed in Colorado so there is much to learn before COGCC can share the new rules. They would like to collaborate with industry to help define timeline. As to writing other rules, COGCC issued a request through SOGRA group, working with the IOGCC to look at flaring rules and suggest changes. Some of the biggest challenges the panel members shared from operators regarding implementing higher efficiency controllers include proof of performance in the field, associated costs, availability of technology.

Highlights from full notes are as follows:

- Anadarko, designs facilities to minimize flaring (gathering lines/compressor stations), no sales gas is flared. They are also a midstream company.
- North Dakota capture targets – Current – 88%, 2020 = 91%
- Economics are built around liquids, market doesn't incentivize upfront infrastructure.
- Many options but not always able to implement on smaller sites and/or by smaller companies.
- COGCC working through new SB -181 bill (defining, understanding changes, etc.)
- CDPHE is being directed to look for transmission sector (didn't have to do this before).
- Regarding destruction efficiency 95-98%. Some technologies see higher (99%). Permit only allows 98% max.

- DOE has FOA with \$15 million for R&D – potential to respond to challenge of getting to a Zero Emission Site.

Key points:

What might it take to get to Zero Emissions?

- What does a Zero Emissions Pad look like?
- How can a Zero Emissions Pad be replicated?
- COGCC is looking to work together with industry (operators and service providers) for a full understanding of new rules and regulations (e.g. SB 181).

Canonsburg, Pennsylvania – June 18, 2019:

The fourth and final FIST-2019 workshop was held at the Hilton Garden Inn - Southpointe in Canonsburg, PA on June 18, 2019. The format for this work differed from earlier workshops as there isn't a tremendous amount of flaring reported in the Marcellus/Utica regions.

The format was as follows:

Welcome/Introduction
Issues Discussion – operator and regulatory perspectives
Technologies Panel Presentations
Around the Room / Wrap-Up

Registered attendees and panel members included representatives from industry (including Range Resources, TransCanada, EdgeMarc Energy and various local consultant/companies), regulatory/state agencies (such as the *West Virginia Department of Environmental Protection*, *Pennsylvania Department of Environmental Protection* and the *Ohio Dept of Natural Resources O&G Division*), technology companies (included panel members *Siemens*, *Capstone Turbine*, *EcoVapor Recovery Systems*, *LPP Combustion*, *Questor Technologies*, *Certarus*, *Calvert Energy* and *Heartland Water Technology*, Hexagon Lincoln and Citizens Resources), NGOs and industry trade groups (Clean Air Task Force, Marcellus Shale Coalition, and the Petroleum Technology Transfer Council [PTTC cohosted the event]) and academia (West Virginia University – WVU). Additionally, attendees from and affiliated with the US Department of Energy/National Energy Technology Laboratory attended (DOE/NETL, KeyLogic Systems). *Italicized organizations participated in the different panel discussions.*

Opening panel discussed issues with a reference to a recent Society of Petroleum Engineers (SPE) publication from Range Resources titled, '**Production Facility Emissions Reduction in Liquids-Rich Shales: An Update.**' Project team members, presenters and organizations in the FIST-2019 program are not affiliated and did not contribute to this publication. It was referenced and discussed due to its relevance to the topic of this workshop. Some initial talking points were shared from various participants to inspire attendees to ask questions and provide comments on topics they felt were key issues, areas they'd like to know more about and material they felt should be addressed in the forthcoming updated white paper. For example:

- What causes flaring in this region? Is it due to liquid rich production?
- In reference to the aforementioned paper, Range Resources looked at traditional steps (condensate straight to the tanks), adding a Vapor Recovery Tower to allow pressure to drop, then added an additional compressor to pull liquids off of tower (multi-stage compression) and they saw pressure drops. They were able to pull flash vapor off of tower to avoid issues with oxygen.
- Condensate in this region is very, very light.
- One solution was to evolve as much as pressure out of tanks.

- Range Resources looked at lock down (thief) hatches on tanks. When closed, common problem relates to sealing/lid gasket which can cause issues. (These hatches still have pressure release valves.)

An inspector from the WV Department of Environmental Protection shared a slide/image of the current permitted O&G sites in West Virginia. Key points include:

- Many flares/sites do not have flow meters. Some companies use GSR to track. In West Virginia, the western part of the state is primarily wet gas and the eastern side is dry.
- Some operators use vapor recovery towers while others use GPUs (2) wherein the second GPU heats and the VRU captures that gas.
- There are ~1300 permitted sites in West Virginia currently.
- Permits are automatically required for flares ('control tank emissions').
- State Rule 6 covers temporary flaring.
- There is no volume limit on flaring.
- The burden of compliance is on the company.
- Pre-production activities do not require a permit.
- WV DEP is always looking for bmps and best designs. They try to share this information with others as well.
- Optical cameras are used to find leaks.
- Material selection is an issue. Often, the cheapest is used which doesn't hold up as well.
- Inspections (and reporting) are done by hand, not digitized.

Regulatory bodies (commissions, DNRs, EQs, etc.) need to work together to share best practices and technologies.

The PA DEP speaker spoke next. He encouraged all to embrace a culture of safety. Key points:

- Industry should work toward a reputation based upon "Flawless Performance." To do so would alleviate some fear and misconceptions about industry.
- Only ~3 sites flare in PA during completions. It's very rare to have any in PA. Of these three sites, specific causes were noted.
- He'd like to see an 'emissions free' site in PA and wants to learn more about technologies that might lead to such a site.
- Perhaps unconventional can help conventional (practices, lessons-learned, etc.)
- Point: a mass (conventional) site abandonment has begun (with more anticipated).
- He'd like to know more about how to address shut in gas.

Attendees were asked to share what was learned and/or found most interesting/surprising, what needs more information or demonstration and/or what would should be noted in updated white paper.

(Names/companies are not identified.) Key points include:

- Learned about mobile power generation, and about WV; what's hard and/or easy to do
- Learned about power generation options – would like feedback from drillers on how they are using it
- Turbines have come a long way. Found the produced water treatment discussion very interesting
- Attendee is looking for alternatives for flares. It's not too popular in Ohio. Would like more information/updates on standby power
- This was a wonderful experience with open communication/conversation among all. There is no one magic silver bullet. Urges others to take a systems approach. Also, look at the different approaches from different states.

- It'd be nice to see the various best management practices as well as the gaps that need to be addressed.
- Technologies seem geared for larger companies. Smaller companies need access, too. Work on scalability and economics for smaller producers.
- It's a hard sell when we focus on the environmental benefits. It's easier to sell cost savings. Point to DOE: Consider the electricity generated from waste heat and maybe help incentivize, recognize emissions profiles.

Regulatory solutions cuts both ways. Infrastructure issues are still a problem. Operators have to work with 3rd parties. Sometimes BLM, USFW, others delay infrastructure development (takes too long) when you have a divided environment (industry vs. environmental). Hopefully we can come up with solutions (win/win/win). We want to flare less, it's money, not waste. There are lots of challenges, we need to all collaborate.

- Denver Workshop Operator Attendee

Industry Survey, November/December 2018

In December of 2018, the FIST team sent a survey to collect information on flaring issues, technologies and potential solutions. The survey was also designed to assist with the development of regional workshops to ensure they would be valuable to both participants as well as the FIST project. The survey was sent to approximately 2500 recipients. 13 Respondents included one operator, one government/regulatory agency, two university/researchers, three engineering/consulting firms and six service providers (Operators – 7.69%, Government/Regulatory – 7.69%, University/Researchers – 15.38%, Engineering Firm/Consulting Firm – 23.08%, Service Provider, 46.15%).

The first question posed to participants asked about their primary areas of operations as related to flaring issues. Several responses indicated they (individuals and/or companies) are focusing on the reduction and/or elimination of flaring by finding alternative uses for flared gas such as utilizing the waste heat to power organic Rankine cycle systems, generating electricity (CHP), or use of wellhead flare gas in a system to evaporate wastewater onsite. One respondent reported their focus is the quantification of flare emissions, air permitting, emissions reductions from venting and specifying the type of flare to use. Insight on regulatory aspects were also shared, noting that operators are required to fill out a C-129 form, which is a request for exception to the no-flare rule. Once regulators receive and approve the request, operators can flare the well for 90 days.

Several companies shared details on their current strategies to address flaring, predominately capturing and processing wellhead gas. Some details were provided by service providers in this area, such as:

- Well site gas processing with over 60 MMcfd of modular and mobile well site processing;
- Removing NGLs and impurities and compressing it into trailers for transportation to activities able to use natural gas (e.g. engines, power generation, pipelines, etc.);
- Working with operators to incorporate more passive biological control approaches instead of flares;
- Providing waste gas incineration services to E&P companies to help eliminate/reduce flaring;
- One company's technology that enables operators to beneficially reuse wellhead flare gas;
- Use of vapor recovery compressors for storage tanks (when feasible), reducing pressure drop between separator and storage vessels, and optimizing facility operations;
- Power generation using engines/turbines, thermal to power;

- Organic Rankine cycle generator and a boiler that burns flare gas to heat water needed for ORC;
- One company's technology called the Phoenix Series T system.

Survey takers were asked if there are local, state or federal regulatory barriers in monetizing flared, stranded or underutilized natural gas at their sites. The responses, as expected, varied by state. North Dakota is the only state with flare capture regulations, however the respondent indicated that Wyoming may soon have regulations to this effect in 2019. In Texas, road restrictions and taxes were listed as potential barriers. Gas is often taxed as an 'on road' product. Other responses to this question referred to the time allowed to flare and that there are no positive incentives found by either state or local agencies. One respondent commented, *"Most of our partners indicate that flaring is the most common and well understood approach to emissions control. Support from regulatory agencies for other more innovative approaches will be needed."* Another respondent stated that there currently is minimal cost or penalty for flaring as well as minimal incentive to recover vapors if cheaper to flare gas.

The technology section of the survey was next, with one designated for operators only and one for service providers only. In the operators only section, the goal was to ascertain if operators are currently implementing, testing and/or interested in specific strategies. In the service providers only section, the goal was to see what is being commercialized, tested, and/or where interest was within the same technologies. The table at the end of this document represents the data collected. With both operators and service provider companies, 'Testing' was not selected. From the responses to Operator's Only Section, one operator based in Oklahoma responded, noting they are implementing Power Generation (using reciprocating engines; gas turbines; micro-turbines; and organic Rankine cycle technologies). They also noted they are interested in Gas Processing and Mini-LNG – Gas to Liquids (small scale liquefaction plant). A follow-up question asked if there are other solutions and/or technologies they are currently implementing and/or testing. The operator responded:

- Patented high pressure separation
- TEGs
- Sterling engines
- New methods for NGL liquids recovery along with biological control
- Data, stack top monitoring and emissions testing

Service providers were asked about other technologies with which they have field experience. The following notes were provided:

- Biological emission control;
- Fuel and emission reductions for reciprocating engines;
- Waste heat to power, waste gas incineration;
- Commercially proven treatment of wastewaters from numerous segments (industries) including O&G, landfill leachate, and power generation. This company also stated they can utilize thermal energy directly from the flare or use exhaust from a reciprocating engine or turbine;
- Trace gas detection

Question 9 of the survey asked if there are other technologies participants believed needed further investigation and/or demonstration. The responses were:

- Small scale GTL technologies;
- Heat exchangers as an option to flaring – if the flare suppliers could supply an HX inside their kit, it would eliminate the need for a boiler;
- Fuel and emissions reduction for reciprocating engines;

- The Heartland Concentrator should be evaluated in multiple regions of the U.S. The technology is ideal in regions where water disposal costs are higher and wellhead gas is available;
- Plugging as well as financial assurance;
- Integrated long path methane detection

Lastly, respondents were asked if there are other technologies to increase the value of NG at or near the wellsite. The responses were indicated that it isn't as much as new technologies but obtaining acceptance of existing technologies within field operations of producers. Enhanced NGL recovery and utilization, storage, and converting to electricity were issues posed by some respondents. One respondent suggested that stranded gas could possibly be used to run wind turbines at night at windfarms along with more gas generators to generate electricity to run equipment at well sites as ways to increase the value of NG at or near wellsite.

Not all respondents provided answers to questions in the Technology section. However, the researcher respondents, government/regulatory and engineering/consulting firms indicated their areas of interest. Power Generation and Mini-GTL were highest of interest to all survey respondents. Interest in Mini-LNG and Gas Processing tied as next highest of interest, followed by Compressed Natural Gas.

Key Findings

Throughout the workshops, meetings, survey and other information gathering methods, various themes emerged with the highest priority being:

1. Infrastructure – the lack thereof, the need for gathering lines, pipelines, power lines, and other near to well markets. Infrastructure (gas processing facilities, pipelines, etc.) is the key to long-term flare reduction at scale. Accelerating the permitting process for the infrastructure would have a major impact on reducing the flaring of natural gas.
2. Communication – need for various regulatory agencies (environmental, natural resources, utilities) to communicate as well as the need for various organizations within an operating company to fully collaborate (production, drilling/completion, gas sales, etc.)
3. Technology – need to further identify, develop and demonstrate technologies on a regional basis. There are technologies that can be of use to reduce the amount of flared gas on a short-term basis.

The following is a list of key findings from the workshops, survey and other efforts:

- In Denver participating operators discussed the fact that wellhead gas is inconsistent in its composition and therefore in its BTU delivery.
- Dealing with the liquids is very expensive when thinking about transportation, stability and price.
- Dual fuel engines that are being used to power drilling rigs can use CNG, but they still need diesel because of variation in the load on the engines.
- For significant horsepower needs, operators still need diesel, the CNG does not deliver the necessary power.
- It takes a lot of processing to remove impurities and raise the volume of gas to the correct pressure of 3600 psi for transport and once at the wellhead the pressure has to be reduced to go into the engine.
- Operators state that Bakken's #1 problem is gas supply because of significant pressure drop in the system when gas processing plants are put in the gathering system.
- LNG will be very important but it is much more expensive to make the economics favorable. Need to build a big plant and have cooperation from multiple producers.

- Multi-well drilling and production pads are advantageous because gas produced from one well can be converted to CNG and used for drilling successive wells. The CNG can also be used for heating facilities and frac fluid.
- Designing the gathering lines to include new technologies in an effective way is a possible area for technological advance.
- Another problem with many of the shale oil plays is the rapid increase and decline in gas volume over time. This makes it more difficult to plan and utilize a supply of gas that is ephemeral in nature.
- Royalty issues are becoming a big deal. If you produce and use on the same site that is provided for in most leases, but if you use the gas from one lease to help drill the well on a separate lease then you have a problem. A royalty payment may be required.
 - Who is responsible to pay, the company producing the oil and associated gas, the company using the gas to create the CNG and transport to next site? Laws have not caught up with the variety of situations that are being encountered.
 - Continental is avoiding the problem in the Bakken by paying full royalties on everything being produced including gas that is flared.
- Need for modeling software to deal with multiple wells with flow variations and variations in consumer requirements.
- Need a steady stream of production.
- Need to find ways to deal with slugs of liquids (water and hydrocarbons).
- On public and federal lands there is a long process to get approval for flaring gas. Government is royalty holder. For these reasons, some companies don't want to be involved with federal land.
- Distance from infrastructure – distance and capacity of pipelines, pressure requirements at the pipeline. Hydrocarbon liquids are a real problem. There is currently a glut, pipelines are full and trucking the liquids is expensive.
- Distinguishing the type of liquid can be critical. Condensates produced from gas wells can be sold outside of the country because the prohibitions on selling oil products do not apply.
- CO₂ regulation by EPA is important. CO₂ is a byproduct of methane burn.
- Aggregate facilities and save money – create coops. These are difficult to negotiate between companies but could ultimately create the economy of scale to make some of these technologies work for smaller companies.
- Distance between pad producing energy and pad needing energy. Once again reducing this distance through pad drilling can be critical.
- Permitting new technologies - the EPA prefers known technologies and tend to be very slow to approve new technology, creating a bottleneck.
- Fugitive emissions: There was some conflicting discussion of what FLIR guns (infrared cameras) are showing around wellsite tanks. Discussion that FLIR guns are actually showing VOCs not methane.
- Uses for the methane: heat, cool, water vaporization, lighten hydrocarbons. Use the heat produced from flare gas to vaporize waste water to avoid injection or heat fluids for hydraulic fracturing.
- Issues surrounding variations in gas production related to rapid decline. Economic factors make it less feasible to build significant gas gathering lines if production is going to drop. Once again having multi-well pads can mitigate these costs.
- One participating company operates 60-70% with field gas or LNG; the goal is to have no diesel on site.
- The cost of conversion to LNG and to winterize the equipment were factors to be considered.
- The change in engine technology, with more dual-fuel options, has been beneficial.
- Regarding the source of field gas used as on-pad fuel was addressed by the operator working with both high- and low-pressure gathering systems, so they can gather and compress flare gas on-site

with a mobile unit, use what they need and sell remaining product, or put it in line with produced gas for sale.

- Initially, water flows back but as the volume of water decreases and gas flow increases, a decision point is reached that flaring is necessary. The second decision point is reached when gas goes into the line and flaring is stopped.
- In regard to pressure that is too high to complete their program limiting pressure to 80% of burst pressure, using a bigger wellhead, or running an oscillation sleeve could provide positive results.
- The electricity is regulated in PA, but not in WV, so it is easier to get electricity onto the grid in PA, is harder in WV.
 - More importantly, the low cost of electricity produced by coal-fired power plants results in a lower market price for any electricity generated on-site for sale.
 - This drastically effects the economics on on-site production of electricity for sale versus on-site use.
- Dealing with the liquids is very expensive when thinking about transportation, stability and price.
- Variability of gas quality and volumes
- Major barriers to electrification of gas
- For significant horsepower needs, operators still need diesel, the CNG does not deliver the necessary power
- Multi-well drilling and production pads are advantageous because gas produced from one well can be converted to CNG and used for drilling successive wells; or generate power to supplement operations.
- Need a steady stream of production.
- Need for modeling software to deal with multiple wells with flow variations and variations in consumer requirements.
- Gas prices and excess of NGL price has made it more difficult to make NGL process a no cost to the operator. Penalties in N Dakota for flaring provide cost incentives.
- Challenges for right sizing and cost recovery are the result of rapid gas rate declines, variability to BTU and liquid variability and non-steady flow rates has led to small modular designs.
- Systems being developed with variable sizes of power generation options from 60 KW for on-site power to 40 MW from fracturing operations.
- Using gas from flaring for powering dual fuel engines has several challenges: inadequate supply for drilling, no infrastructure, variability of gas quality, issues of gas slippage when used in the engines. There is a need for emissions control systems.
- Issue with using a 'temporary' solution for a permanent problem.
- Implementing a mini grid that grows as an asset is developed could be a solution but dealing with forming a co-op, leases, royalties and landowners make it difficult.
- Pipelines charge operators more for accepting field gas.
- Power purchase pricing and access must be fair and allow this as a cost-effective option
- Perspective: Give pipeline owners incentives to accept field gas. Give companies payback options for flare capturing technologies
- Incorporate incinerator technology to maximize gas combustion during flaring when required or is necessary.
- NSPS OOOO (QuadO) and OOOOa are a federal regulation that have identified gas that is now being flared. Ease of pipeline installation would improve infrastructure which would increase natural gas production and provide a mechanism for reducing flaring. Since natural gas has a smaller CO₂ footprint than other fossil fuels, that would increase the use of NG.
- The issue is not incentives for the operators but to have incentives for local infrastructure to build systems to gather this scattered flare gas. Natural gas pipelines are not the answer here what is needed is new innovative ideas, have local electrical co-ops buy back electricity or create local

co-ops to gather isolated gas and process into some liquid form that is easier to transport than natural gas (CNG or LNG).

TECHNOLOGIES

There are many technologies used throughout the oil and gas industry. A comprehensive table of technologies is included in the appendix. A few examples include:

- Onsite power generation with ranges from kilowatt to megawatt systems.
- Use of waste heat to produce onsite power through a closed-loop organic Rankine cycle to boil working fluids into gas.
- Novel gas turbine technologies that can handle a wide range of BTU gas and liquids.
- Use of new clean energy technologies in conjunction with stranded/wasted gas to generate power.
- Removing CO₂ out of the natural gas to be re-injected for EOR purposes
- Gas-to-liquids process through the use of SMR and Fischer-Tropsch to create synthetic crude, Ethanol, Methanol, and/or Formalin.
- Mobile compressed natural gas systems that can be leased.
- Using flare gas to produce Nitrogen Fertilizer
- Turbines to produce electricity for onsite and sales
- Installing temporary gathering lines or converting gas to CNG or LNG to power drilling and hydraulic fracturing operations.

The selection of what technologies/processes should be considered or combined with others, are based on multiple factors, including:

1. Production and Economic Factors
 - End Product – What will be produced (electricity, liquids, CO₂.)
 - Production Rates – What produced gas rates will the technology handle, what volumes of gas and rates will the technology produce the end product at.
 - Geography and land topography
 - Storage options
 - Access to power and gathering lines
 - Transmission/compression costs
 - Permitting timing and costs
2. Gas Factors
 - Gas Treatment – Is gas required to be treated, who treats the gas?
 - Gas composition and quality tolerance needed for the technology
 - Compliance with environmental regulations?
3. Applications
 - Use – What will technology be used for? (Power onsite equipment, sell electricity to grid, produce liquids for sell, increased recovery)
 - Currently Used/Technical Readiness – Is the technology being used? Has it been through a field trial or tested at any level?

- States/Regions of Operations – Onshore, Offshore, US only, International, Extreme Weather...
- Access to other users of power
- Additional Support Required – Who provides maintenance, general care, and monitoring?
- Economics – Capital and Operations Costs

Various flaring mitigation technologies may be synergistic with other emission reduction efforts.

Various sources were used to obtain information concerning technologies that are related to mitigating flaring and meeting corporate emission goals.^{12,13,14,15,16}

Research Needs

There are research needs that have been identified through the program. These are related to developing the technologies and processes that may monetize the natural gas in an economic manner.

Zero Emissions

Increasing demand for fossil energy resources is projected to continue¹⁷. Industry has recognized the importance of addressing environmental aspects of production, transport and use by mitigation of emissions, including emissions from flaring. Numerous new commercial products are now available to capture emissions. There is also a wide range of products available for methane detection and quantification.

As identified in the Denver, Colorado workshop, there is a need for research through the use of a series of field laboratories to demonstrate methane mitigation technologies that may be deployed. These sites can also demonstrate, test and evaluate methane emissions detection and quantification technologies under a range of representative field conditions, representative of various natural gas transportation infrastructure unit operations that include but are not limited to: pipelines, valves, pneumatic controllers, compressors, tanks, sensors, etc.

The research effort could also develop and apply an independent testing protocol that can compare the performance of superior methane emission leak detection and emission quantification technologies to the current federal environmental regulatory reporting requirements. In so doing, a transparent, scientifically rigorous, and defensible validation procedure/protocol for comparing the performance of new technologies tested in the field under field conditions will be developed using independent and unbiased data gathering, analysis and testing mechanisms. This research data should then be readily available to end users. As demonstrated in the program discussed in this report, regional workshops are one of the many effective ways to transfer this information.

¹² Global Gas Flaring Reduction Partnership, "GGFR Technology Overview – Utilization of Small-Scale Associated Gas," February 2018.

¹³ World Bank Group, "Global Gas Flaring Reduction – A Public Private Partnership," Report 29554.

¹⁴ Emam, E.A.: "Gas Flaring in Industry: An Overview," *Petroleum & Coal*, ISSN 1337-7027. December 3, 2015.

¹⁵ Oristaglio, M. and Skinner, M.: "Natural Gas Flare Reduction: Case Studies in Russia, Nigeria, and the United States," Senior Essay Presented to Dept. of Geology & Geophysics, Yale University, April 30, 2014.

¹⁶ SRI Consulting, IHS Inc.: "Process Economics Program Report 247B: Small Scale Gas-to-Liquids Technology," December 2011.

¹⁷ <https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf>

There are numerous technologies that have been identified that can be used to mitigate flaring as well as other methane emissions. Technologies to mitigate flaring and emissions may be deployed and measurements/quantification/validation could be performed. A focus should include economics: cost effective CAPEX/OPEX, scalable, modular, reliable.

In addition, there are a range of commercial products available for methane detection and quantification tasks. Colorado State University (CSU) partners with APRA-E to identify and evaluate these technologies.

The objectives of the potential research effort would be to:

- Progress the symbiotic relationship of oil and gas production, technologies that mitigate emissions and technologies that can detect / quantify methane emissions.
- Increase the widespread use of technologies that can mitigate emissions.
- Increase the widespread use of technologies that can quickly, and cost effectively detect and quantify methane emissions, both large and small, across a wide variety of locations, environments and operating conditions, supports the need for a steady stream of new alternatives.
- Evaluate new alternatives against a set of standards so that they can be adopted, revised or discarded as quickly as possible.

Virtual Pipeline Research

A discussion was held at the Canonsburg FIST workshop about the use of ‘virtual pipelines’ wherein the produced gas is compressed and transported by truck to users. A research program may be developed to document the economics of the process.

Research to Expand the Potential to Use Flare Gas to Generate Power

One area for research development would be to engage the flare vendors and support them in the development of a flare that has a proper heat exchange designed into the flare itself – the flare would create hot water advancing a simple opportunity for flares to be transformed into distributed power generation units.

This would be the combination of commercial flare technology married with commercial heat exchanger technology. The result would be an integrated package that forms a new paradigm for beneficial use of flared natural gas. The focus on the demonstration would be to integrate a solution that is a robust combination of technologies that has proper sizing, design and controls and can be deployed relatively quickly. Gulf Coast Green Energy / Electratherm did a demonstration with Hess in 2015 where a boiler was placed in the oil and gas fields in North Dakota and utilized the unused flared natural gas in the boiler to create hot water. The result was a successful demonstration of creating onsite electricity from the flared gas using Organic Rankine Cycle (ORC) technology. A brief video of the project is here [[HYPERLINK "https://electratherm.com/flare-elimination-system-video/"](https://electratherm.com/flare-elimination-system-video/)] [[HYPERLINK "https://electratherm.com/flare-elimination-system-video/"](https://electratherm.com/flare-elimination-system-video/)].

Gas Injection into Shale Formations

A discussion was held at the Midland FIST workshop concerning the potential to use produced gas to enhance recovery from unconventional reservoirs. Some Permian producers are experimenting with injecting natural gas into low pressure reservoirs. Wells are then shut-in to allow the natural gas to seep into the reservoir and mobilize additional oil production.

As illustrated at the SPE Improved Oil Recovery Conference agenda, there are a number of promising research and field demonstration efforts to take use underutilized gas to improve oil recovery. <https://www.spe.org/events/en/2018/conference/18ior/schedule-overview.html>

This process has been used in conventional wells with success. Miscible and immiscible oil recovery in conventional reservoirs using CO₂, N₂, CH₄ has been successfully applied for many years. As unconventional resources mature, there could be widespread use of similar processes where additional research is warranted.

The improved oil recovery (IOR) process is highly dependent upon geology. Compression costs are one of an economic factor. A research program may be developed to characterize formations and optimize the potential of using natural gas to enhance production.

DRAFT